Large-Scale Aerosol Modeling and Analysis

Douglas L. Westphal
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4743 fax: (408) 656-4769 email: westphal@nrlmry.navy.mil

Cynthia A. Curtis
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4022 fax: (831) 656-4769 email: curtis@nrlmry.navy.mil

Annette L. Walker
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4722 fax: (831) 656-4769 email: walker@nrlmry.navy.mil

Document Number: N0001409WX20031
http://www.nrlmry.navy.mil/aerosol

LONG-TERM GOALS

The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles for the entire globe for timely use in planning and executing DoD operations and activities. The fundamental predicted variables are the concentrations of atmospheric aerosol particles responsible for degradation of Electro-Optical (EO) propagation in regions of DoD interest. Post-processors calculate the optical parameters useful in strategic and tactical planning, training, and operational activities. This forecast and simulation capability is also used in theoretical studies of the Earth's atmosphere and has operational usefulness in scientific field campaigns.

OBJECTIVES

The objective of this program is to investigate, develop, and test aerosol initialization, source, and prediction schemes. New knowledge and methodologies will be incorporated into an aerosol data assimilation and prediction system based on observations, aerosol process models, meteorological models, and their error characteristics.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Large-Scale Aerosol Modeling And Analysis**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,7 Grace Hopper Ave, Stop 2,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles for the entire globe for timely use in planning and executing DoD operations and activities. The fundamental predicted variables are the concentrations of atmospheric aerosol particles responsible for degradation of Electro-Optical (EO) propagation in regions of DoD interest. Post-processors calculate the optical parameters useful in strategic and tactical planning, training, and operational activities. This forecast and simulation capability is also used in theoretical studies of the Earth?s atmosphere and has operational usefulness in scientific field campaigns.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

The approach to the problem of aerosol and EO extinction prediction follows the approach used in numerical weather prediction, namely real-time assessment for initialization of first-principles models. The Naval Research Laboratory has developed a new capability for forecasting the global and regional concentration of atmospheric particulate matter and the subsequent effects on visibility. The regional model (COAMPS®[1]/Aerosol, with the aerosol software embedded in-line with the atmospheric model) became operational during Operation Iraqi Freedom (OIF). The separate and more independent global model, the Navy Aerosol Analysis and Prediction System (NAAPS), became operational in October 2005 and is executed after the global atmospheric model NOGAPS[2], rather than as an integral part of it. Nonetheless, regardless of the technical approach, together these models predict the concentration of the dominant visibility-reducing aerosol species up to six days in advance anywhere on the globe. NAAPS and COAMPS are particularly useful for forecasts of dust storms in areas downwind of the large deserts of the world: Arabian Gulf, Sea of Japan, China Sea, Mediterranean Sea, and the Tropical Atlantic Ocean. NAAPS also accurately predicts the fate of large-scale smoke and pollution plumes. With its global and continuous coverage, NAAPS is invaluable in filling the gaps in observations of aerosol particles and visibility, which are largely provided from polar-orbiting satellites, and extends our understanding of aerosol particles and their impact on Navy operations. However, validation studies indicate that the forecasts would benefit from increasing the resolution and the number of species and the implementation of aerosol data assimilation.

WORK COMPLETED

A. Walker continues development and improvement of NRL's unique high-resolution dust source databases (DSD). A new version for East Asia that utilizes the MODIS[3] Dust Enhancement Product to distinguish elevated dust over land from other components of the scene and to identify the many small, eroding point sources that form the heads of point source plumes has been completed and transitioned to PMW-120 for advanced development, demonstration and validation prior to operational implementation. A paper describing the methodology of the NRL high-resolution (1 km) dust source database applied to Southwest Asia has been published (Walker et al., 2009).

NAAPS has been improved by the addition of an aerosol data assimilation capability, developed with other ONR and PMW-120 funding. The operational NRL Atmospheric Variational Data Assimilation System (NAVDAS) has been modified and developed to process and assimilate MODIS Aerosol Optical Depths (NAVDAS-AOD; Zhang et al., 2008). The assimilation capability has been converted for use in a daily research mode by C. Curtis and evaluated for impact, both for the scientific impact and for operational impact by D. Westphal. It has been approved by our Administrative Model Oversight Panel (AMOP) for implementation at the Fleet Numerical Meteorology and Oceanography Center (FNMOC), the central-site production center for atmospheric modeling. NAVDAS-AOD became operational in September 2009 and is the only operational global aerosol data assimilation system in the world.

---

[1] COAMPS® is a registered trademark of the Naval Research Laboratory. COAMPS is the Coupled Ocean/Atmosphere Mesoscale Prediction System, used for regional and local application.
[2] NOGAPS is the Navy Operational Global Atmospheric Prediction System, the Navy's operational global weather model.
[3] MODIS is the Moderate-Resolution Imaging Spectroradiometer on board NASA's Terra research satellite.

RESULTS

In the paper by A. Walker et al., COAMPS modeling results in SW Asia are used to show that the improved specification of erodible land surfaces by use of a high resolution DSD allows COAMPS to accurately model the evolution of individual dust plumes and better forecast the onset and end of dust storm occurrence (i.e. low-visibility conditions; Figure 1). Statistical analyses of the visibility predictions and dust storm occurrence show simulations using the high resolution DSD are capable of predicting individual plumes (Figure 2) and have the lowest false alarm rates and the highest total prediction skill among the other DSDs that were considered (Figure 3). This work contributes to the growing base of knowledge concerning the global dust cycle by identifying and mapping point sources in one of the world's foremost dust producing regions.

To date, the modeling objective for NAAPS has been to provide the best aerosol distributions for EO propagation, especially in support of the Target Acquisition Weapons Software (TAWS) used for strike warfare by the tri-service DOD agencies. Over the past few years, the NAAPS capability has been demonstrated by D. Westphal to the Senior METOC[4] Officer for the Naval Security Group and to the Meteorological and Environmental Pathways to and from the Intelligence Community (MEPIC) at a series of meetings. This action has resulted in their acceptance of NAAPS as the baseline source of aerosol parameters for their applications, namely scene correction. The standard NAAPS and Forecast of Aerosol Radiative Optical Properties (FAROP) output fields will satisfy their requirements with little change. The intelligence community (IC) also requires quantitative evaluation of the uncertainty and error in NAAPS analyses and forecasts. This work is already in progress.

Google Earth visualization of NAAPS forecasts has been improved by C. Curtis with the addition of the animation of the forecast fields and the ability to perform vertical slicing. These features are in addition to the existing capability of visualizing the individual components, fire locations from the Fire Locating and Modeling of Burning Emissions (FLAMBE) project, and other related parameters.

Our plans to embed NAAPS inside NOGAPS may need to be put on hold pending the outcome of the decision on the potential use of the United Kingdom Meteorological Office (UKMO) Unified Model (UM) by NRL and FNMOC as a replacement for NOGAPS. An in-line model would allow better coupling to the dynamical forcing and would enable research on direct, semi-direct, and indirect forcing on numerical weather prediction (NWP), which are some of the major uncertainties in climate research. The UKMO has several aerosol models, two of which are in-line. These are called CLASSIC (similar to NAAPS) and UKCA (more detailed chemistry). CLASSIC is used by the Hadley Centre for climate runs and used regionally. UKCA is practical only for climate runs. In the event of the adoption of the UM, NRL would evaluate, modify, and otherwise optimize CLASSIC or UKCA to meet Navy needs by focusing on the species important to EO propagation and de-emphasizing chemistry calculations.

IMPACT/APPLICATIONS

NAAPS helps to satisfy the Navy's long-term goal of a predictive capability for aerosol particles and EO propagation. The forecasts of aerosol concentration are distributed via NIPRNET and SIPRNET for use by DoD forecasters, operators, planners, and aviators (http://www.nrlmry.navy.mil/aerosol/). The model output is processed by FNMOC and converted into the fundamental optical properties

[4] METOC is an acronym used to refer simultaneously to "Meteorological and Oceanographic" in the Navy community.

required to calculate EO propagation. These properties are used to populate the Tactical Environmental Data Server (TEDS) and subsequently used by TAWS to calculate slant-path visibility. The aerosol forecasts also are used to correct satellite retrievals of sea surface temperature (SST) by the Naval Oceanographic Office, thus improving tropical forecasts.

NAAPS also provides tools for the 6.1 and 6.2 aerosol research communities and the academic community. NAAPS data continues to be used in interactions with the research community appearing in peer-reviewed and conference papers. Over the year, collaborations have occurred between NRL and the University of Valladolid (Spain), University of California at San Diego, University of Helsinki, Scripps Institute of Oceanography, the University of Warsaw, Colorado State University, USGS and others. NAAPS forecasts enhance NRL's continued participation in field programs and will give us further opportunities for collaboration and access to important validation data.

NRL was invited to describe the NAAPS system of models and lessons learned at the Global and Regional Earth-system Monitoring using Satellite and in-situ data (GEMS) Final Assembly at the Jülich Research Center in Germany during March 2009. NRL was the only non-GEMS participant and was invited since NRL developed the world's first operational global aerosol model.

During the 2009 Senior METOC Officer (SMO) Conference the Central Command (CENTCOM) SMO identified Dust, Smoke, and Aerosol (DSA) forecasting as a capability gap within CENTCOM. Further, during the 2009 Weather Impact Decision Aids Conference, DSA forecasting was addressed by both the operational and research community as needing additional emphasis. To address the DSA forecasting issue the Joint METOC Board Steering Group assigned the Operations and Effects Working Group to hold a two-day workshop between the Services to identify the capability gaps. NRL was invited since the laboratory is the lead in 6.1-6.4 work on DSA. The outcome of the meeting was a list of short-, mid-, and long-term action items that would improve DSA for the Services. Many of the items are 6.2 in scope and already are being addressed by this work unit or will be considered: the investigation of the significance of dust re-suspension in SW Asia, KML versions of products, development of a tri-service dust source database, developing criteria and methodology for defining success in forecasting, improvement to training, and development of a roadmap for future improvements.

TRANSITIONS

NAAPS has been operational at FNMOC since October 2005. Improvements to NAAPS (as developed in this work unit) are transitioned to FNMOC via 6.4 funding provided by PMW-120. Initial transition of NAVDAS-AOD to 6.4 and FNMOC occurred in FY08. NAVDAS-AOD was approved for operational implementation at FNMOC on September 30, 2009 by AMOP.

RELATED PROJECTS

ONR 6.2 "Application of Earth Sciences Products" supports improvements in NAAPS physics and model initialization. The implementation of NAAPS, NAVDAS-AOD, FLAMBE and FAROP at FNMOC are supported by 6.4 funding from PMW-120 for "Large-scale Atmospheric Models", "Small-scale Atmospheric Models", and "Satellite Aerosol Data Assimilation." This funding also supports development and generation of products for use by the fleet. The NRL 6.1 Accelerated Research Initiative "Physics of Cloud Variability" uses NAAPS data and products for initialization, investigations and validation, as does the NRL 6.2 base project "Atmospheric Correction for

Oceanography.” NAAPS forecasts and simulations are used for several other applications: FAA Volcanic plumes, NASA “Vertical Dust Distribution Analysis and Lidar Data Assimilation”, NASA Biomass-cloud interactions, scene correction, and ocean color and SST correction.

REFERENCES

2008, Zhang, J., J. S. Reid, **D. L. Westphal**, N. L. Baker, and E. J. Hyer, A system for operational aerosol optical depth data assimilation over global oceans, *J. Geophys. Res*., 113, doi:10.1029/2007JD009065.

PUBLICATIONS

2009, **Walker, A.** L., M. Liu, S. D. Miller, K. A. Richardson, and **D. L. Westphal**, Development of a dust source database for mesoscale forecasting in southwest Asia, *J. Geophys. Res*., **114**, D18207, doi:10.1029/2008JD011541 [published, refereed].

2009, Pratt, K. A., P. J. DeMott, **D. L. Westphal**, C. H. Twohy, K. A. Prather, S. M. Kreidenweis, and A. Heymsfield, Direct observation of biogenic and dust particles in high altitude ice clouds, *Nature Geoscience*, DOI: 10.1038/NGEO521 [published, refereed].

2009, Niemi, J. V., S. Saarikoski, M. Aurela, H. Tervahattu, R. Hillamo, **D. L. Westphal**, P. Aarnio, T. Koskentalo, U. Makkonen, H. Vehkamäki, and M. Kulmala, Long-range transport episodes of fine particles in southern Finland during 1999-2007, *Atm. Env*., **43**, 1255-1264 [published, refereed].

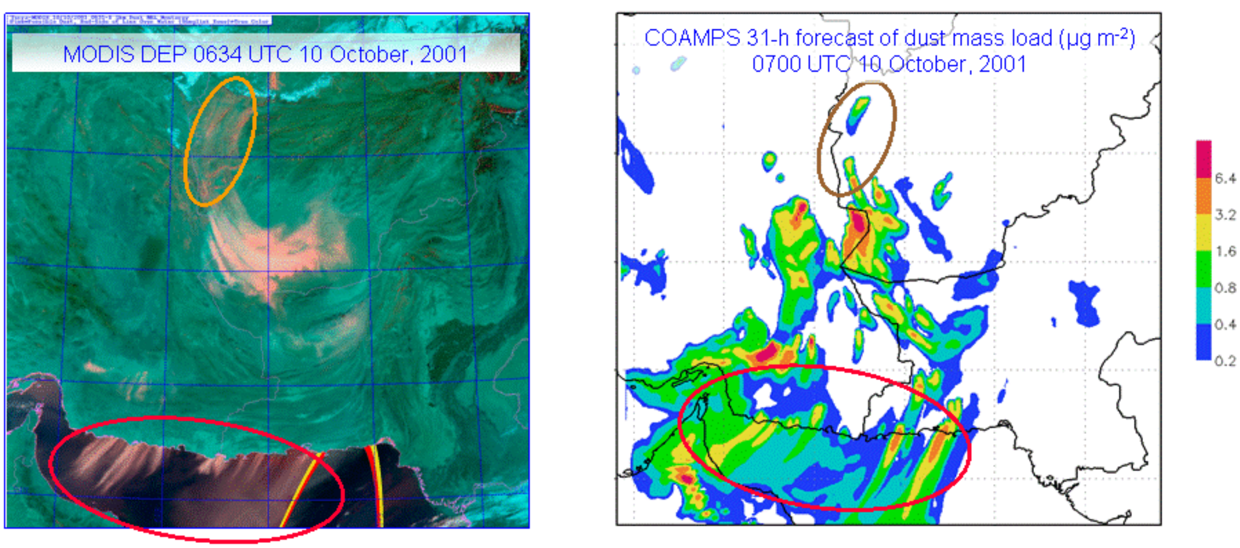

Figure 1. (left) MODIS Dust Enhancement Product (DEP) for 0634UTC, 10 October, 2001, showing fine-scale dust plumes originating in the Zabol Region of Afghanistan and along the southern coastline of Iran and Pakistan. The elevated dust plumes appear in a pink hue in the DEP. (right) 31-hour COAMPS forecast of the dust loading (units of micrograms per square meter, scale at right) for the same area, valid at 24 minutes later, 0700 UTC, 10 October, 2001 showing that the model, when using the DSD, is able to forecast the individual dust plumes that were observed. (Walker et al., 2009.)

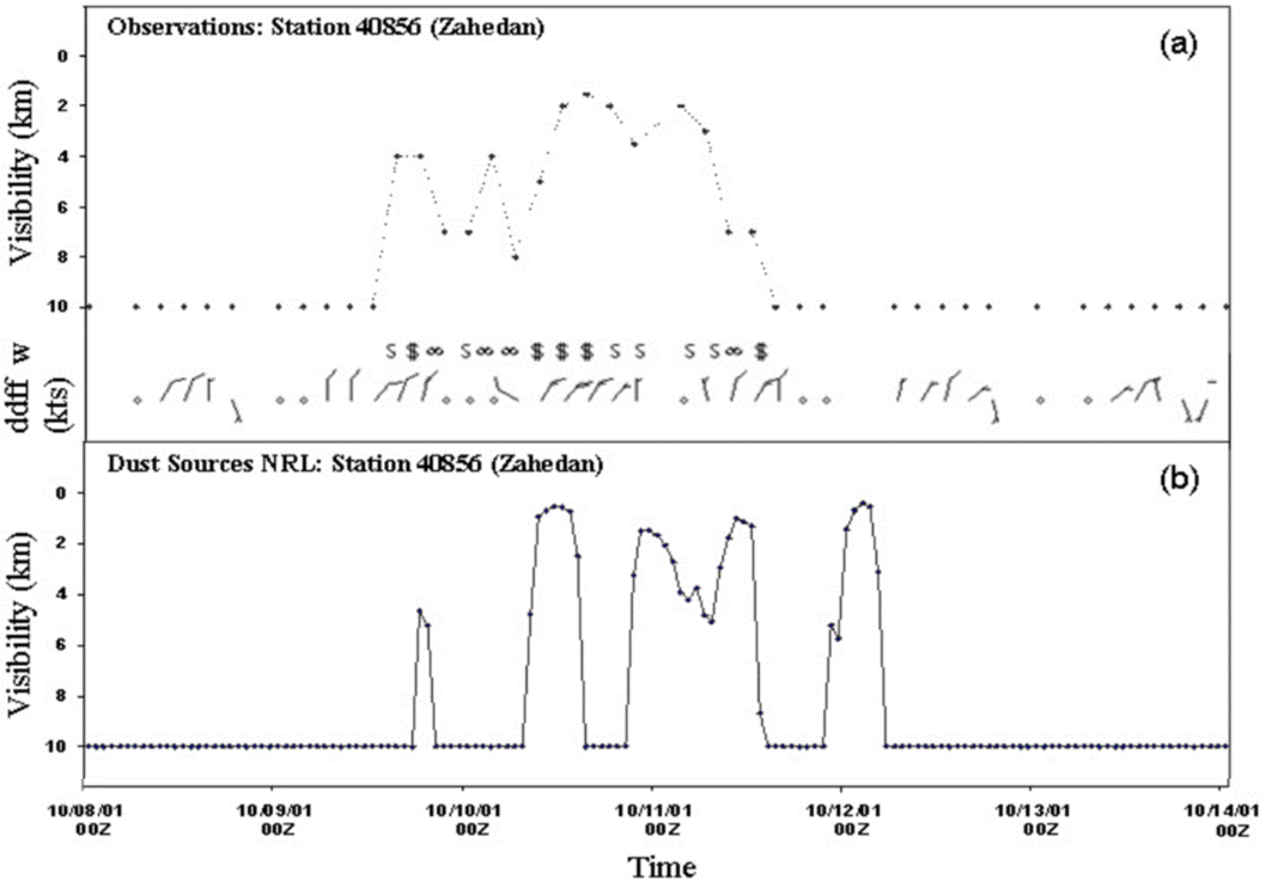

Figure 2. (top) Surface observations of visibility (in km), current weather ('w') and wind speed ('ddff', in knots) at station Zahedan (WMO number 40858) in Iran, just downwind of the Zabol region for the period of 0000 UTC, 8 October, 2001 through 0000 UTC, 14 October, 2001. The observations show high-visibility conditions initially, then a dust event with visibilities of 2 km starting at 15 UTC, 9 October and lasting until 1500 UTC, 11 October. (bottom) COAMPS forecast of visibility for the same period showing a dust storm with a similar starting time and an ending time of 0900 UTC 12 October. (Walker et al., 2009.)

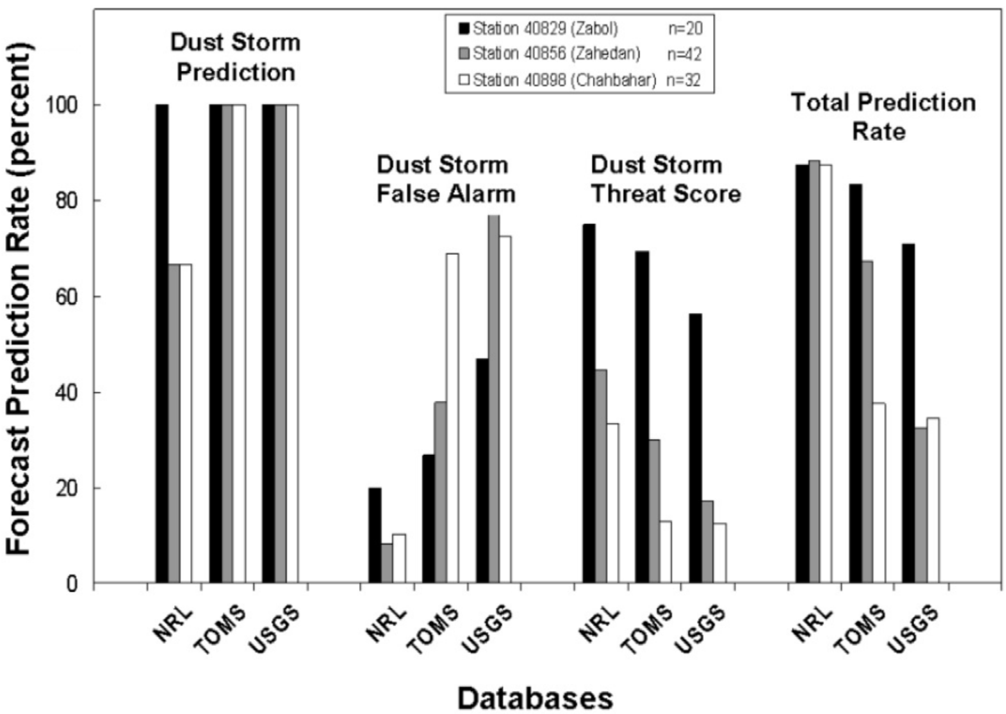

Figure 3. Comparison of COAMPS dust storm forecast skill using three different dust source databases: the high-resolution DSD, the TOMS-USGS hybrid, and the USGS. The skill is measured with the prediction rate, false alarm rate, threat score, and total prediction rate at three Iranian stations (Zabol, Zehadan, and Chahbahar) for 0000 UTC 8-14 October 2001, where n is the number of observations at each station used in analysis. The statistics show that the DSD provides the best scores at all of the stations. (Walker et al., 2009.)